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A detailed household carbon footprint analysis using expenditure accounts – Case of Flanders (Belgium)

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ABSTRACT

Within national carbon footprints, households are responsible for bulk of the overall direct and indirect carbon emissions. Also, the wide spread in household characteristics (e.g. size, income, age) leads not only to different carbon footprints, but also includes an underlying difference in the contributions of the consumption domains. Therefore, it is essential that policies focussing on climate change mitigation should be customized to take into account these differences. In this study we quantify which socio-economic household characteristics are associated with a higher than average per capita carbon footprint and which consumption domains trigger this higher than average carbon footprint. The results are quantified for the regional case study of Flanders (Belgium). To obtain a better estimate of direct and indirect emissions we draw upon the EXIOBASE2 multi-region input-output dataset combined with the regional input-output data and detailed regional household budget survey data. From our analysis, it is also clear that the decomposition of the carbon footprint into the relevant consumption domains reveals insights that are absent when comparing total carbon footprints. Overall we find that there is a clear link between the income distribution and the carbon footprint of consumption, a finding that returns frequently in literature for both developed and developing countries. However, this income distribution is closely related to several underlying other socio-economic categories (e.g. level of education and household size) which do provide further insights useful for policy as they reveal important socio-economic aspect which needs to be considered.

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1. Introduction

While average national carbon footprints are an indication of the required efforts individual countries must undergo in reducing carbon emissions, there can be considerable differences in carbon footprints depending on socio-economic disparities in society. With individual households are responsible for the bulk of overall direct and indirect carbon emissions (Baiocchi et al., 2010; Ivanova et al., 2016), policies customized to take into account these household differences in carbon footprints are essential. In this respect, the increase in inequality and aging of the baby-boom generation are two important patterns that not only affect the fabric of our society, but are also inextricably linked to changes in consumption patterns and the associated carbon footprints. A better understanding of the composition of overall carbon footprints is thus fundamental to implement the required policies to reducing the overall footprint.

In this light, several studies have looked at the importance of household characteristics when disaggregating carbon emissions according to the relevant socio-economic constituents (Baiocchi et al., 2010; Büchs and Schnepf, 2013; Druckman et al., 2011; Druckman and Jackson, 2009; Kerkhof et al., 2009; Reynolds et al., 2015; Weber and Matthews, 2008; Wiedenhofer et al., 2016; Wier et al., 2001). Several of these studies have found substantial disparities in the carbon footprint associated with consumption between the different types of households. For instance, Weber and Matthews (2008), Druckman and Jackson (2009) and Wiedenhofer et al. (2016) all reported large differences in carbon footprints when comparing the households with the lowest and the highest footprint. Kerkhof et al. (2009) found that the environmental impact increased with household expenditure. While the environmental impact rose more than proportionally for some measures such as smog formation, it increased less than proportionally for other such as climate change. Rather than exploring the discrepancies of carbon footprints associated with consumption,

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Büchs and Schnepf (2013) analysed the income elasticity of UK households relative to several types of emissions. While a rise in household income is always associated with increasing emissions, transport and indirect emissions react more than proportionately to income changes, whereas emissions related to housing are generally less elastic. This implies that carbon taxes will affect diverse socio-economic groups disparately. Wiedenhofer et al. (2016) add to differences in the household carbon footprint due to income inequality the difference in carbon footprint between urban and rural residents for China. There results show that urban residents, 53% of the Chinese population, induce 75% of the national household carbon footprint in 2012.

The literature has thus made significant headway in improving our understanding of national carbon footprints. Nevertheless, there are still a number of ways in which one can improve upon the existing estimates. One important aspect is to make use of more detailed and country-specific data to account for the increasing role of international trade. Druckman and Jackson (2009) found a rising foreign contribution to indirect household carbon emissions over time, showing the merit of more accurately accounting for this foreign production chain that produces consumption goods. However, the availability of data at the time restricted the number of foreign regions that could be taken up in the analysis. Recently, the availability of environmentally extended multi-region input output tables (EEMRIO) has greatly expanded the analytic possibilities. In this paper, we draw upon the EXIOBASE2 MRIO dataset (Tukker et al., 2013; Wood et al., 2015) to obtain a better estimate of direct and indirect emissions. Ivanova et al. (2016) also applied the EXIOBASE2 dataset to analyse the material-use, land-use, water-use and greenhouse gas emissions linked to household expenditure. However, the focus of their paper was on estimating the elasticity of expenditure with respect to the average environmental impact in a sample that contains a large cross-section of countries.

Steen-Olsen et al. (2016) are closest in set-up to our paper. They combined the Norwegian consumer expenditure survey with EXIOBASE2. However, while their focus is on the evolution of the carbon footprint and on the relation between different income groups and the carbon footprint, we exploit the full detail of the Flemish household budget survey to further decompose the carbon footprint according to different socio-economic categories. In this way, we obtain greater insight into how the carbon footprint varies according to different characteristics of households such as employment status of the household reference person, the age of the household reference person, the size of the household, the residential ownership status, etc. This is particularly pertinent for policy purposes as varying consumption patterns across different socio-economic groups form relevant parameters that need to be considered in the formulation of effective and socially acceptable climate policy.

We also perform our analysis on a regional rather than a national level. This improves the accuracy of our calculations as the use of a regional dataset increases the level of disaggregation to fully reflect the Flemish economic characteristics. Moreover, using more disaggregated data also allows us to control for socio-demographic differences that may exist within countries and that could be particularly relevant for determining the carbon emissions associated to consumption (Baiocchi et al., 2010). By linking this regional dataset to a global model we also account for global production networks. Moreover, the case of a small open economy, such as Flanders in which trade is an important economic characteristic, is testament to the added value a detailed regionalised MRIO can bring to environmentally related policy analysis.

The main research question of this paper is stated as follows: "*Which socio-economic household characteristics are associated with a higher than average* per capita *carbon footprint and which consumption domains trigger this higher than average carbon footprint?*". To analyse this question we compare the average carbon footprint of a household according to different household characteristics (size, age, number of children, etc.). Based on the outcome we then define those factors that are associated with a higher average per person or per household carbon footprint. Next, the consumption domains are analysed to understand the underlying expenditures resulting in the higher than average carbon footprint.

The next section describes the methodology and the data that we use. Then, we report the results and analyse the differences between different socio-economic groups. In the discussion, we address the relevance of these results for policy purposes and, finally, relevant conclusions are drawn that follow from the analysis.

2. Method and data

In the following paragraphs we define and explain the concept of the carbon footprint, the input-output methodology applied to calculate it, the expenditures of households and the different types of households. The results encompass the global warming potential based on the IPCC guidelines (IPCC, 2014) and are expressed in ton CO_2-eq. per household or per person per year, depending on the household characteristic under consideration.

The carbon footprint measures the global greenhouse gas emissions[1] emitted in value chains linked to products consumed by domestic final demand in one year. The footprint includes direct emissions by households, indirect or embodied flows across production networks including imports, and excludes exports and associated indirect flows of exports. Following the emission typology of Lebel et al. (2007), these footprints include direct emissions and deemed emissions (i.e. embodied emission of imported products), but exclude responsible and logistic emissions (i.e. embodied emissions of exported products). The exclusion of exports (i.e. responsible and logistic emissions) puts the focus on the consumption perspective: local emissions related to exported products are not taken into account, while deemed emissions are included.

The computation of the carbon footprint is based on input-output analysis (IOA). This analysis approximates the emissions resulting from final demand expenditures along its entire preceding network of value chains. The general formula that we apply in this paper to compute carbon footprints, *CF*, is based on the Leontief inverse and can be represented as (Matthews et al., 2008):

$$CF = \mathbf{g}\left(\mathbf{E}_{\text{coef}}\mathbf{L}\mathbf{f} + \mathbf{e}_{\text{HH, direct}}\right)$$

where

- $\mathbf{g}$ is a row vector of GWP_{100}-values: 1 for carbon dioxide, 28 for methane, 265 for nitrous oxide and 0 for all non-greenhouse gas emissions;
- $\mathbf{E}_{\text{coef}}$ is a matrix with emission coefficients, rows indicating the different emissions types and columns indicating the sectors;
- $\mathbf{L}$ is the Leontief-inverse, $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$, where $\mathbf{A}$ is the matrix product of a matrix $\mathbf{Z}$ containing the interindustry deliveries and the inverse of the diagonalized output vector $\mathbf{q}$, $\mathbf{A} = \mathbf{Z}\,\hat{\mathbf{q}}^{-1}$, and $\mathbf{I}$ is an identity matrix;
- $\mathbf{f}$ is the final demand column vector including household consumption expenditures; and

[1] GWP is calculated as GHG emissions including carbon dioxide (impact factor 1), methane (impact factor 28) and nitrous oxide (impact factor 265) (based on the GWP_{100}-values).

- $\mathbf{e}_{HH,\ direct}$ is a column vector of the direct household greenhouse gas related emissions.

Here, we restrict **f** from the IO-database to household consumption (so excluding consumption by non-profit institutions, governmental consumption, investments and changes in inventories and valuables), which is later further specified by consumption domains (COICOP-classification[2]). Also, the extension scalar of direct household emissions is later specified per consumption domain. To calculate the footprint of households in Flanders, this paper applies an IOA (Eurostat, 2008). Specifically, we use a regional input-output table for Flanders and link this via the import to a globally covered multi-region input-output table: if Flanders imports a product, the production chain of this product is traced back in the multi-region input-output table. In this way, we are able to link the final demand in Flanders to the entire production network preceding it. The method applied for the integration of the regional Flemish database in a world input-output model is described in Christis et al. (2017). Both the regional model for Flanders and the multi-region model are used in their full detail without modification. Only the import and export of Flanders are linked to the producing or consuming actor in the multi-region model. The method is closely related to the multi-scale multi-region input-output model by Bachmann et al. (2015). The difference is that the methodology of Christis et al. adds a sub-region to an existing MRIO, while Bachmann et al. replace a nation with its sub-regions. However, both methodologies are similar as they both account for different sectoral representations. The combination of a local input-output model and a multi-region input-output model allows for an analysis based on available local data, adapted to the local economic characteristics and including global sectoral data. This is particularly relevant for determining the footprints of non-autarchic economy carbon footprints which are determined both by local and global specific characteristics. The main shortcomings of the IOA for this type of application is the level of sector aggregation. Aggregated sectors present the 'average' production structure which can differ substantially from the production structure of a specific product, resulting in under- or overestimations of the carbon footprints. Therefore, the results are restricted to estimation for the macro-economic products (product groups) and provide no details on microlevel products.

For the methodology described above we use the Flemish EE-RIO table (2010 data) which is part of the interregional input-output database of Belgium. It contains 124 sectors, nine final demand categories, interregional and international trade, and six value added categories. Environmental data in the extension tables comprise the emissions data necessary to calculate the carbon footprint. In the input-output model of Flanders, consumption is defined according to the residential (national) concept i.e. household expenditure of all residents in Flanders and abroad. The input-output tables follow the ESA95 rules.[3]

We then link this Flemish IO table via the trade link to EXIOBASE2 (2007 data; industry-by-industry tables). EXIOBASE2 is a global EE-MRIO database produced in the context of the project 'Compiling and Refining of Economic and Environmental Accounts' (CREEA). The database covers 200 products and 163 industries for 43 countries and 5 rest-of-world regions. The extension tables include 15 land use types, employment broken down into three skill levels, 48 types of raw materials and 172 types of water use. Flanders is indirectly included in the EXIOBASE2 database via Belgium (Tukker et al., 2013; Wood et al., 2014).

This study compiles a final demand matrix for households in Flanders for each household characteristic. This matrix describes for a given household characteristic the expenditures of households at a detailed level based on the COICOP-classification. These matrices are compiled from the original final demand vector available in the input-output model, but reconstructed for each household characteristic using the household budget survey. The datasets and procedure are explained below.

The basis for the expansion of the final demand vector of Flemish households is the household final consumption expenditure account, which is part of the national accounts and covers expenditures incurred by households to acquire consumption goods and services. It excludes expenditures devoted by households to the acquisition of dwellings, which constitute an investment in fixed assets, and those devoted to the acquisition of valuables[4] (Eurostat, 2008). The accounts use the COICOP-classification: a classification of individual consumption expenditures incurred by households according to their purpose. The household consumption expenditures are classified in 12 domains (level 1), which can be further disaggregated into more detailed COICOP levels 2 and 3.

The household budget surveys (HBS; see Eurostat (2003)) are the main source behind the compilation of the household final consumption expenditure in national accounts. HBS for Belgium are available both at a national level and at the level of the three regions (Flanders, Wallonia and Brussels). The surveys mainly focus on consumption expenditure and describe the expenditure structure of different types of households (i.e. household characteristics) at a detailed COICOP-level. For the case of Flanders we use the HBS provided by Statistics Belgium that contains consumption data for different household characteristics. Specifically, the HBS reports average expenditure per household and per year by:

- the income groups using deciles;
- the number of elderly (>65) per household (household with no elderly, households with only elderly and mixed households);
- the number of children (<16) per household (households with children and households without children);
- the number of active people per household (households with 0, 1 or 2 and more active people);
- the statute owner or renter;
- the age of the reference person (households with a reference person younger than 30 years old, between 30 and 39, 40–49, 50–59 or older than 60 years);
- type of household (single, 2 adults, 3 or more adults, single with dependent child(ren), 2 adults with dependent child(ren) or 3 or more adults with dependent child(ren));
- the size of the household (single, 2, 3, 4, 5 or 6 or more persons);
- the employee statute of the reference person (self-employed, employee, unemployed, pensioner or other non-active); and
- the age of the oldest person in the household (the oldest person is younger than 65 years, between 65 and 74 years or above 75 years old).

Often, statistical agencies divide households in different categories by defining a reference person.[5] Here, the reference person is defined as the person contributing the most to the financial income of the household. In the case where two people have equal

[2] Classification of individual consumption by purpose.

[3] The European System of Accounts is the system of national accounting used within the European Union. It has now been succeeded by the ESA2010 framework.

[4] Valuables are stores of value that cannot be used for production or consumption, such as works of art, precious stones and metals, jewels.

[5] For the construction of the national accounts, dividing households into groups based on the overall income of the household is preferred over the use of a household reference person. However, practical limitations in data assembly can necessitate the use of a reference person approach.

contributions to the financial income of the household, the oldest of these two people is defined as the reference person.

However, the data from the household budget survey is not directly transferable to the household expenditures in the input-output tables format. Data in household budget surveys is defined in purchasers prices inclusive non-deductible VAT. While, the IO-tables are expressed in basic prices (separating taxes and subsidies), and as such distinguish between the trade margins and product value for the products purchased by households. It means that trade margins are allocated to the trade sectors and the product value is allocated to the sector (or sectors in case of multiple products) producing the product. In order to match the two, allocation tables are available. These tables allocate the final demand vector of households in different consumption categories e.g. food, housing, and as such links the consumption categories (COICOP-classification) and the purchases from sectors (NACE-classification), both domestic purchases and imports. Allocation tables link the trade margins to the value of the product and combine the purchases of products of different sectors into one COICOP-category (e.g. bread and cereals (01.1.1) is a combination of products of different sectors). The allocation of product (or product groups) to consumption domains is based on the definitions of the COICOP-domains as described by the UNSD (UNSD, 2003).

An important drawback of the applied methodology is that the IOA provides only uses one carbon footprint intensity per product group. Although households can consume different products within the same product group, the IOA allows not to reflect this different in consumption pattern within one product group into the carbon footprints. For example, higher income households may consume higher quality meat product compared to lower income households. However, as the model only provides one (average) carbon footprint intensity per euro of meat products, this difference in consumption pattern is not translated into a difference in carbon footprint. The increasing quality orientation of households with rising income is neglected using our methodology (Girod and De Haan, 2010). This results in an overestimation of the carbon footprint for the households systematically choosing for higher quality products, but also underestimates the impact of households systematically choosing for cheaper low quality products.

Allocation tables for Flanders are developed (via a bottom-up approach) by the Federal Planning Bureau and are structured in different consumption categories (40 according to COICOP 3-digit division for 2010) and assigned to industries that are identified by the NACE-classification conform the IO-tables. In a next step, the consumption categories are extended to 59 categories according to COICOP 3-digit classification, based on the allocation tables for 2003 that distinguish 387 COICOP categories. The allocation tables for 2003 were also developed by the Federal Planning Bureau, based on the Household Budget Enquiry (HBE) for Belgium (Bilsen et al., 2010).

The attribution of direct emissions from households ($\mathbf{e}_{\mathrm{HH,\ direct}}$ from the carbon footprint equation) to the COICOP-consumption domains of housing (fuel use for heating and cocking) and transport (fuel use for road transport). The attribution is based on a bottom up analysis, using regional energy statistics (energy balance). These direct emission coefficients (defined per euro expenditure of the corresponding consumption domain) are linked to household categories based on expenditures.

In conclusion, the results in the manuscripts are based on input-output analysis using a input-output model compiled from:

- household expenditure data from the household budget survey data for the year 2010;
- a regional input-output model for Flanders of data year 2010;
- a multiregional input-output model Exiobase v.2 for data year 2007.

3. Results

The results are structured according to the different household characteristics that are available in HBS and presented in Fig. 1. The average household in Flanders consists of 2.378 persons including on average 0.446 children (<18y). 39% of the households have children, on average 1.742. The yearly expenditures of the average household sum up to 36,737.22 EUR and our analysis reveals that average household expenditure is linked to a carbon footprint of 33.1 ton CO_2-eq/yr. Based on estimates in the literature, we can make a direct comparison with other European countries. UK households have been found to emit on average 20.18 tons CO_2-eq./yr over the period 2006–2009 (Büchs and Schnepf, 2013) and 21.5 tons CO_2-eq./yr in 2004 (Druckman and Jackson, 2009). Norwegian households emitted 22.3 tons CO_2-eq./yr per average household in 2012 (Steen-Olsen et al., 2016). Of these studies, only the latter applies EXIOBASE2. The reported numbers of Büchs and Schnepf (2013) and Druckman and Jackson (2009) likely differ strongly from our estimates for Flemish households as we apply the EXIOBASE2 MRIO while they use different and less extensive I/O models to calculate the total average CO_2-eq./yr embodied by consumption. Indeed, using the EXIOBASE2 dataset, Ivanova et al. (2016) found that the average per capita footprint of UK citizens is higher than that of Belgian citizens possibly indicating that the UK household carbon footprints are lower bound estimates of the actual carbon footprint. In contrast, Wiedenhofer et al. (2016) show that Chinese households only have an average per capita carbon footprint of 1.7 tons CO_2-eq./yr in 2012 (however, very rich urban dwellers have a carbon footprint of 6.4 tons CO_2-eq.).

Fig. 2 panel (a) reveals that the three COICOP-categories with the highest carbon footprint are housing, water, electricity, gas and other fuels (04; 36%), transport (07; 21%) and food and non-alcoholic beverages (01; 16%). Although the order of the categories contributing most varies, the importance of these three categories in the average household carbon footprint has been reported elsewhere in the literature as well (Steen-Olsen et al., 2016).

In what follows we will report on each of the household characteristics individually and discuss our general findings. Although we also performed the carbon footprint calculations based on the number of children in a household and the age of the oldest person of the household, these will not be further discussed in the text as they overlap with some of the other household subdivisions that are already included in our discussion.

3.1. Income deciles

The average income per decile varies between 10.890 EUR per year for the lowest income decile to 84.146 EUR per year for the highest income decile. The increase in the carbon footprint is not proportional to this rise in income. For the lowest income decile the

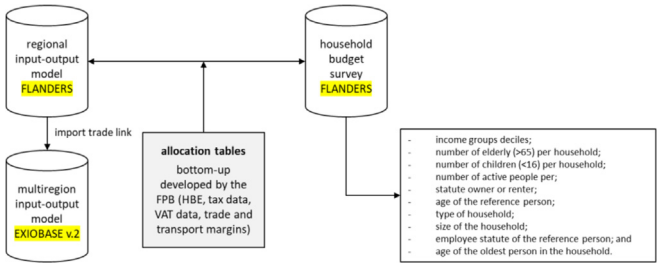
regional input-output model FLANDERS
household budget survey FLANDERS
import trade link
multiregion input-output model EXIOBASE v.2
allocation tables
bottom-up developed by the FPB (HBE, tax data, VAT data, trade and transport margins)
income groups deciles;
number of elderly (>65) per household;
number of children (<16) per household;
number of active people per;
statute owner or renter;
age of the reference person;
type of household;
size of the household;
employee statute of the reference person; and
age of the oldest person in the household.

Fig. 1. The carbon footprint estimations are based on IOA using a regional and multiregion input-output model in which regional household demand is extended using HBS-data.

Fig. 2. Summary of the results of the household carbon footprint per COICOP-domain for Flanders (2010). The average household carbon footprint (a) is further detailed across household characteristics (b–h). Note that panels (a), (b), and (d) provide footprints per person, while panels (c), (e), (f), (g) and (h) provide footprints per household.

carbon footprint equals 19.8 ton CO_2-eq./yr per household. It then rises monotonically across the deciles to 50.0 ton CO_2-eq./yr per household for the highest income decile. Hence, while there is a factor 7.7 difference in average income between the lowest and highest income decile, we only observe a factor 2.5 difference in carbon footprint between these household categories. This is evidence of the 'relative decoupling' effect (Sommer and Kratena, 2017).

The carbon footprint of each COICOP category increases in tandem with the rise in income of the household (Fig. 2, panel (b)). The COICOP category contributing most to the carbon footprint for all income deciles is housing, water, electricity, gas and other fuels (04). However, the absolute increase in the carbon footprint of this COICOP from the lowest to the highest income decile (with a factor of 1.6) masks that the relative contribution of this category to the overall carbon footprint gradually erodes over the different income deciles. The largest absolute increase between the lowest and highest income decile is found for COICOP categories transport (07; +7.4 ton CO_2-eq.), food and non-alcoholic beverages (01; +7.4 ton CO_2-eq.) and housing, water, electricity, gas and other fuels (04; 4.1 ton CO_2-eq.). These three categories are thus not only the most important contributors to the overall average carbon footprint, but they also account for 60% of the total difference in the carbon footprint between the lowest and highest income category.

3.2. Employee status of the reference person

While there has been considerable focus in the literature on the disparate consumption patterns of different income classes and their associated carbon footprints (e.g. Sommer and Kratena (2017); Büchs and Schnepf (2013); Girod and De Haan (2010)), much less has been reported on carbon footprint differences for other socio-economic indicators. However, from a policy perspective these are equally interesting as income deciles are made up of heterogeneous population groups. One other socio-economic factor influencing consumption-based carbon footprints is the employee status of the household reference person, to which we turn our attention now (Fig. 2, panel (c)).

The total carbon footprint per person of a household for the different employee statuses of the reference person is comparable across the household categories, except when the reference person of the household is retired as they have a higher per person carbon footprint of 16.6 tons CO_2-eq./yr per capita. On the other side of the spectrum, the self-employed category shows the lowest per person carbon footprint of 12.2 ton CO_2-eq./yr per capita. The other three categories are comparable to the self-employed category with 12.5 ton CO_2-eq./yr per person in the other non-active category, 12.9 ton CO_2-eq./yr in the employed person category and 13.0 ton CO_2-eq./yr in the unemployed person category. The expenditures per person are comparable across the categories, varying between 12.581 EUR to 14.559 EUR per person per year, except for the pensioner category having an average expenditure of 18.107 EUR per person per year. The size of the average household, varying between 1.6 and 1.7, is comparable between the categories unemployed, pensioner and other non-active, but is higher for the employee (2.7) and self-employed (3.3) categories. The average high carbon footprint of the pensioners category results from relatively high expenditures per person and a lower average household size. The higher average carbon footprint is mainly related to housing, water, electricity, gas and other fuels (04) and to a lesser extent to food and non-alcoholic beverages (01). Aside from the smaller composition of the household, the large contribution of housing, water, electricity, gas and other fuels can likely also be assigned to the greater amount of time spent indoors by pensioners.

3.3. Type of the household

When we divide the households into types according to the number of adults and children, one would anticipate considerable discrepancies in carbon footprints between the different types. This is indeed what we observe (Fig. 2, panel (d)). One clear takeaway from our results is that the carbon footprint rises with the number of adults in the household. Also, households with children have a higher carbon footprint compared to the same household without children. Given these facts, households with one single adult and no children have the lowest carbon footprint of 20.9 ton CO_2-eq./yr and households with 3 or more adults and children are at the other end of the spectrum with a carbon footprint of 42.9 ton CO_2-eq./yr. Adding children to the average households results in a higher carbon footprint: on average + 9592 ton CO_2-eq./yr per household or +5506 ton CO_2-eq./yr per child. However, it is clear that the increase in the carbon footprint is not proportional to the number of persons. It is thus interesting to note that while transport (07) and housing, water, electricity, gas and other fuels (04) are the predominant consumption factors driving the increase in the carbon footprint across household types, the latter factor constitutes a much larger fraction of the overall carbon footprint of single adults compared to households with three adults or more with children.

3.4. Size of the household

Fig. 2 panel (e) takes a closer look at the effects of the size of a household on the carbon footprint. Note that this part shows results per capita rather than per household as was the case for the type of the household. One can see that while an increase in the size of the household can be linked to an increasing carbon footprint, the average carbon footprint per person decreases with an increasing household size. A household consisting out of a single adult without children has an average carbon footprint of 20.9 ton CO_2-eq./yr, while this is only 6.8 ton CO_2-eq./yr per person in a household of six or more persons. The per person carbon footprint decreases with 23% from a single to a household composed of two people, with 21% from a two to three persons household, with 16% from a three to four persons household and with 14% from a four to five persons household. These results suggest that there are certain 'economies of scale' and advantages of sharing that eventually result in a lower per person carbon footprint when household size increases. The two consumption domains that are mainly driving this result again are housing, water, electricity, gas and other fuels (04) and transport (07). While the carbon footprint resulting from food and non-alcoholic beverages (01), clothing and footwear (03) and recreation and culture (09), hotels and restaurant (11) also show minor signs of decreasing, they are overall fairly independent of the household size.

3.5. Number of elderly (>65 year) and number of active people per household

The number of elderly (>65y) and the number of active people per household are combined in a single panel in Fig. 2 panel (f), because these categories largely overlap. This results from the fact that the official retirement age in Flanders is set at 65. Therefore, households consisting only of persons over the age of 65 are fully integrated into the 'no active persons' household category. However, households without active persons can consist of people younger than 65 years old. The group of households in category '2 active persons' are mainly part of the group of households in the category no 65 + persons (except for the small group of households with 3 or more adult persons with 2 active persons and at least one person with an age older than 65). Our results show that the per

person carbon footprint of the average household with no active persons or only 65 + persons are the categories with the highest carbon footprint of respectively 16.3 and 16.5 ton CO_2-eq./yr.

When analysing the differences between the households, it is remarkable that only one consumption domain is responsible for the higher carbon footprint of the average household in categories 'no active persons' and 'only 65 + persons': housing, water, electricity, gas and other fuel (04). Also, the per person carbon footprint of food and non-alcoholic beverages (01) and transport (07) diverge, but less substantially so. For these household categories the per person carbon footprint is higher for food and non-alcoholic beverages (01) and lower for transport (07). The per person carbon footprint of all other consumption domains is similar across the different categories.

3.6. Ownership status of residence of a household

In Fig. 2 panel (g) we divide households into groups according to whether they are the lawful proprietor or the renter of their current residence. The fact of whether a household is owner or renter of the dwelling where they are currently residing, results on average in a similar carbon footprint of respectively 13.6 and 13.3 ton CO_2-eq./yr. However, the underlying consumption domains reveal a difference in the composition. The per person carbon footprint of a household that owns the house is earmarked by a lower contribution to the carbon footprint from housing, water, electricity, gas and other fuels (04; −0.9 ton CO_2-eq./yr), but a higher contribution from transport (07; +0.3 ton CO_2-eq./yr) and food and non-alcoholic beverages (01; +0.3 ton CO_2-eq./yr).

3.7. Age of the reference person of the household

Finally, we look at the age of the reference person in panel (h) of Fig. 2. The age of the reference person has a clear influence on the *per person* carbon footprint of the household. The lowest per person carbon footprint, 10.9 ton CO_2-eq./yr, is found for the average household with a reference person between 30 and 39 years old; the highest per person carbon footprint, 16.7 ton CO_2-eq./yr, is found for the average household with a reference person older than 60 years old. Part of the difference is explained by the household size. For example, the carbon footprint *per household* resulting from housing, water, electricity, gas and other fuels (04) is comparable in size across the different households (not reported in the figures). However, there is a remarkable difference in the *per person* carbon footprint resulting from food and non-alcoholic beverages (01). The categories where the age of the reference person is below 30 years, between 30 and 39 or 40–49 years have similar carbon footprint of respectively 2.0, 1.7 and 1.9 ton CO_2-eq./yr per capita. Nevertheless, this is higher for the two other age categories of 50–59 years and above 60 years with respectively 2.5 and 2.7 ton CO_2-eq./yr.

Looking into detail at the food and non-alcoholic beverages (01) in panel (b) of Fig. 3 shows which underlying product group is responsible for the difference. The expenditures on this category are comparable on a per person basis for the first three age categories although a bit lower for the 30–39 age category, varying between 1690 and 1996 EUR per year. The age groups of 50–59 and older than 60 spend more on this category, respectively 2433 and 2682 EUR per year. The higher expenditures result in a higher carbon footprint. This effect is amplified by a higher share of

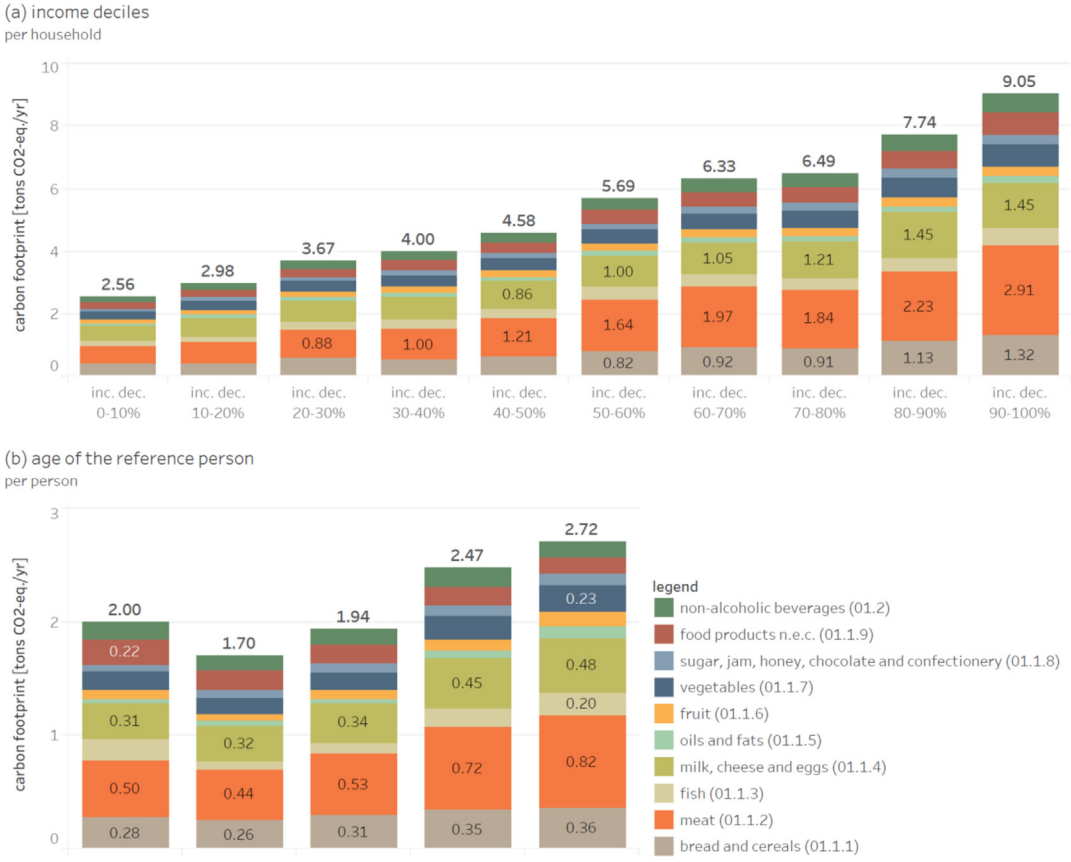

Fig. 3. Summary of the results of the household carbon footprint on the detailed (4-digit) consumption domain food and non-alcoholic beverages (01) of Flanders (2010). The average household carbon footprint for food consumption is further detailed across the income deciles (panel a) and the age of the reference person (panel b). Note that part a provides footprints per household, while part b provides footprints per person.

expenditures on meat products (01.1.2; high carbon footprint per euro) and a lower share of expenditures on food products n.e.c.[6] (01.1.9; low carbon footprint per euro).

4. Discussion

Thus far we have mostly focused on the observed trends in the different socio-economic categories. However, several of these findings are relevant from a policy perspective targeting climate change mitigation. Indeed, Baiocchi et al. (2010) finds that around 74 percent of total climate emissions in the UK can be linked to UK households, making private households a particularly potent target group in the fight against climate change. For comparison, this is 68 percent in Flanders.

One important conclusion from our results is that climate policies also have an important socio-economic aspect which needs to be considered, as also found by Büchs and Schnepf (2013) and discussed by Gough (2013). Housing, water, electricity, gas and other fuels make up the largest component of the household footprint irrespective of the income decile in which the household is situated. Nevertheless, aggressive policies that penalize households for the carbon footprint associated to this consumption category risk aggravating existing socio-economic inequality. Housing and related utilities makes up the bulk of the household carbon budget of low income households, but a much smaller fraction for high-income households. Hence, for policy to be socially tenable and ultimately effective a clear understanding of such sensitivities is required prior to the establishment of policy. Our results indicate that the GHG emission intensity per monetary unit of expenditure decreases with rising income (see also Kerkhof et al. (2009)), making pure carbon taxation based on the carbon footprint of households regressive in nature.

We also find that the per person carbon footprint decreases with rising household size as consumption domains like housing and related utilities and transport are distributed over an increasing number of household members, thereby lowering the per person impact. However, the 'scale economies' and benefits of sharing seem to be mostly limited to these consumption domains. The promotion of a sharing economy could be particularly helpful in combatting household related carbon emissions with respect to transport. Overall food consumption, the carbon footprint of which declines with the size of the household, seems to be mostly insensitive to the number of household members. Addressing the carbon footprint of this category will thus require a different approach. More specifically, it is particularly interesting that the carbon footprint of food consumption is strongly driven by meat consumption and consumption of animal products (e.g. milk). We find that the consumption of meat is an important factor in determining carbon footprint differences related to food consumption between income deciles and age groups. Yet, caution is also warranted in interpreting this result. Girod and De Haan (2010) show that household expenditure data also cover up all quality differences within a certain consumption domain. Particularly, higher income households and older households might consume higher priced meats, so that the average GHG emission intensity of meat consumption hides a lower intensity for higher income groups, thereby overestimating the carbon footprint for high income households and underestimating the impact for low impact households.

From our analysis, it is also clear that the decomposition of the carbon footprint into the relevant consumption domains reveals insights that are absent when comparing total carbon footprints. For instance, renters and dwelling owners have similar average per person carbon footprints. However, decomposing their carbon footprint reveals intrinsic differences that are essential from a policy perspective.

Overall we find that there is a clear link between the income distribution and the carbon footprint of consumption, a finding that returns frequently for both developed (e.g. Steen-Olsen et al. (2016) and Sommer and Kratena (2017)) and developing countries (e.g. Han et al. (2015)) alike. However, the income distribution is closely related to several underlying other socio-economic categories. Richer households will most likely also be older, while older households are in turn increasingly more likely to consist of fewer individuals and thus have higher per person footprints. While we have not addressed these clusters of population groups, these are also worth considering when formulating policy.

5. Conclusion

This paper analyses the carbon footprint of the consumption of Flanders (Belgium) taking into account different household characteristics. It uses the EXIOBASE2 MRIO which has been extended to include this region particularly and integrates the household budget surveys that were carried out at the Flemish regional level. By applying the analysis at the regional rather than the national level we are able to obtain a detailed account of the carbon footprint of a more homogenous socio-demographic group of consumers. Moreover, applying the EXIOBASE2 dataset to a small open economy of Flanders exploits the full power of this dataset in obtaining better estimates for the indirect footprint related to consumption.

Overall, we find that the Flemish households have an average carbon footprint of 33.1 ton CO_2 eq./yr per household or 14.0 ton CO_2 eq./yr per person. This carbon footprint increases monotonically with the income decile in which the family is situated. However, different consumption categories contribute differently to this increase to the carbon footprint. While housing, water, electricity, gas and other fuels generally make up more than half of the total carbon footprint of households in the lowest income decile, it constitutes less than a third of the total average carbon footprint of top income decile households. The low average household size and apparent larger heating requirements cause households where the main income comes from a pension to have a carbon footprint that is around 30 percent higher per person than other households. We also find that the carbon footprint does not rise proportionately to the number of people that are present in the household. When one looks at the per person carbon footprint of larger households, there are certain 'economies of scale' and advantages of sharing household consumption, particularly with respect to housing and related utilities. Remarkably, while the actual composition of the carbon footprint of consumption differs between renters and statute owners of residences, their carbon footprint is similar on average.

Policies generally attempt to directly limit the carbon emissions that result from consumption through several types of interventions. However, this creates shifts in consumption patterns that will offset (part of) the carbon emissions which the policy attempted to reduce. Given its importance in the efficacy of mitigating the climate impact of consumption, we intend to look closer into this rebound effect in future research (Bjelle et al., 2018; Chitnis et al., 2014; Druckman et al., 2011). It is clear that even within a more homogenous socio-demographic region such as Flanders there are still large socio-economic differences within the population that need to be considered in policy design. Moreover, rebound effects are likely to differ strongly between these groups and across different consumption domains, making it a particularly important topic for gaining further insights.

[6] Not elsewhere classified.

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